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LANDSAT D

X-BAND ANALYSIS STUDY

FINAL REPORT

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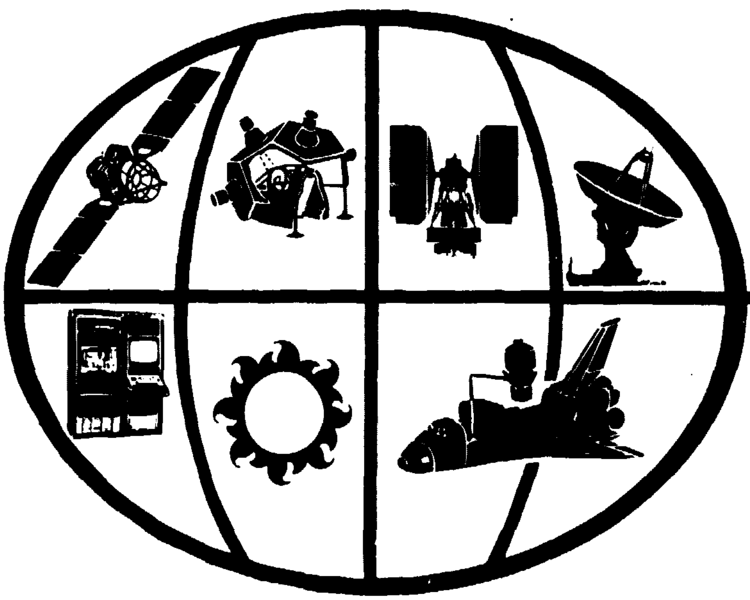

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FINAL REPORT

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1.0 INTRODUCTION

As presently proposed, the Landsat D system will transmit payload data via two links, the TDRSS system and direct readout. The Thematic Mapper direct readout link, previously assigned to a Ku-band carrier frequency, will allow for transmission of image data to domestic and foreign ground stations in realtime. This report investigates the effects of the use of an X-band carrier frequency on the transmission link margins and on the affected ground station equipment.

The specific effects of the X-band carrier frequency allocation on the link margin will be investigated in Section 2. This will include an examination of a Local User Terminal's (LUT) coverage circle radius requirements, detailed elements of the link calculation, and specific spacecraft and ground configurations that would satisfy the link requirements.

The requirements that spacecraft signal acquisition and tracking place on the "front-end" of the ground station equipment will be examined in Section 3.0. Finally, Section 4.0 will investigate the availability of the required ground station equipment and obtain representative costs for these items. The costs considered shall be both for procurement of a new ground station ("front-end" only) and for modification of an existing S-band station to X-band.

2.0 LINK MARGIN INVESTIGATION

2.1 COVERAGE CIRCLE RADIUS

Of primary concern to the operator of a direct readout station is the coverage zone he may achieve from his station. This zone is expressed as the distance, drawn as a great circle, of the limit of coverage from the direct read-out station, and is called the coverage zone radius

Figure 2-1 relates the coverage zone radius to the geometry of spacecraft antenna ground antenna elevation and slant range from the direct readout station to the spacecraft.

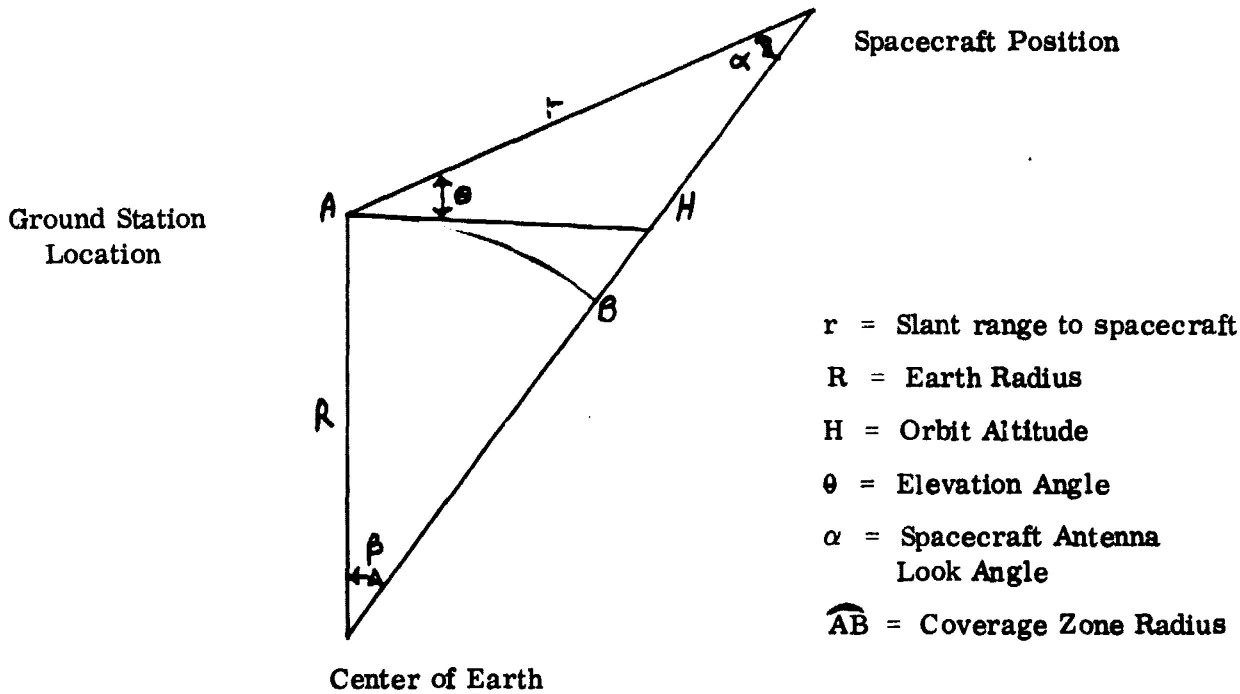

Figure 2-1. Spacecraft - Direct Readout Station Geometry

The geometric relationships between the parameters of interest are given by:

$$\sin \alpha = \frac{R \sin (\pi/2 + \theta)}{R + H} \quad (1)$$

$$AB = R\beta = R(\pi/2 - \alpha - \theta) \quad (2)$$

$$r = \frac{R \sin (\pi/2 - \alpha - \theta)}{\sin\alpha} \quad (3)$$

It can be seen that the primary parameters of spacecraft antenna look angle, slant range to spacecraft, and ground antenna elevation angle can each be expressed as a function of coverage zone radius by manipulation of these relationships.

For a spacecraft altitude of 705 km it can be shown that, if a minimum ground antenna elevation angle of 5° is assumed, the maximum spacecraft look angle, slant range and coverage zone radius are:

Spacecraft look angle	α = 63.8 degrees
Slant range	r = 2573 km
Coverage zone radius	$\widehat{AB}$ = 2362 km

Plotted in Figure 2-2 are the coverage circles available over the United States, assuming 5° and 15° elevation angles from existing U. S. and Canadian ground stations. With a 15° ground antenna elevation angle areas over Texas, Oklahoma and Kansas are not visible, even with all four stations operating. However, when the minimum ground elevation angle is decreased to 5°, the two continental U. S. stations above can just barely manage complete coverage of the United States. Therefore, as a baseline for this study a 5° ground antenna elevation angle, corresponding to the 2362 km coverage circle radius, will be assumed.

2.2 LINK ANALYSIS - EARTH COVERAGE ANTENNA

The establishment of a communications link at a given frequency and data rate, is dependent on three primary parameters: The Effective Isotropic Radiated Power (EIRP) of the transmitter; the signal losses in the path between transmitter and receiver; and the energy per bit to noise density ratio (E_b/N_o) required at the demodulator to achieve the desired bit error rate (BER).

The analysis of the communication link is carried out as follows: First, the ground station required Eb/No is estimated. Next, the intermediate loss factors are established. From there, the required (EIRP) from the spacecraft is computed.

2.2.1 LINK BUDGET

The link power budget is presented in Table 2-1 which contains references to the appropriate sections of the report where each item is discussed.

The budget establishes the required EIRP which is expressed as:

$$\text{EIRP required} = (Eb/No) + Ls + Lp + La + K - (G/T) + 10 \log (DR) + M$$

Where

Ls = free space loss - dB

La = atmospheric loss - dB

Lp = pointing and polarization loss - dB

K = Boltzmann's constant = -198 dBm $J^{o}K^{-1}$

Eb/No = Energy per bit to noise density ratio for 10^{-6} bit error rate - dB

Table 2-1. Link Budget

Parameter	Discussed In Para.	Value	
		LUT Elev Angle = 5^{o}	LUT Elev Angle = 90^{o}
Eb/No Required - dB	2.2.2	13.6	13.6
Data Rate (DR) - dB - BPS	2.2.2	79.2	79.2
Space Loss (Ls) - dB	2.2.3	178.9	167.7
Pointing Loss (Lp) - dB	2.2.4	0.25	0.25
Polarization Loss (Lpo) - dB	2.2.5	0.5	0.5
Atmospheric Losses (La) - dB	2.2.6	4.0	2.0
Boltzmanns Constant (k) - dBm $J^{o}K^{-1}$	-	-198.6	-198.6
System Margin (M) - dB	2.4	3.0	3.0
LUT Sensitivity (G/T) - dB $^{o}K^{-1}$	2.2.7	-32.1	-32.8
EIRP Required - dBm	2.2.8	48.8	34.9

This link budget is based on a Bit Error Rate of 10^{-6} for Differentially Encoded QPSK at a Data Rate of 84 MBPS and for Local User Terminals having Elevation Angles of 5^{o} and 90^{o}.

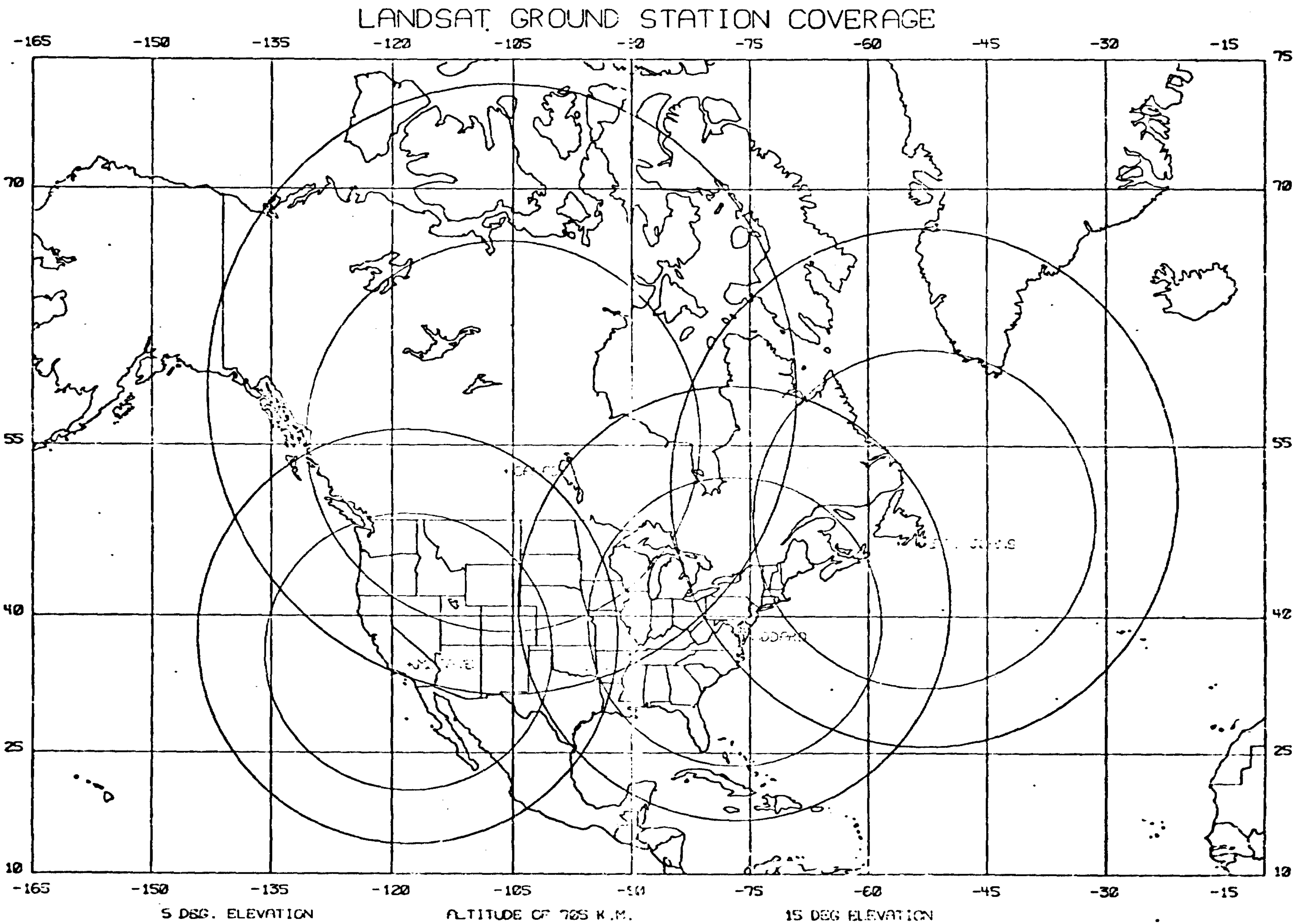

Figure 2-2. U.S. Current and Planned Coverage Zones

DR = Data rate in bits per second

G/T = Antenna/receiver sensitivity factor - dB $^{o}K^{-1}$

M = System margin - dB

2.2.2 (Eb/No) REQUIRED

Differentially encoded QPSK is assumed. Including an allowance for modulator and demodulator losses gives the following required Eb/No for use in the link calculation

Theoretical Differentially Encoded QPSK at 10^{-6} Bit Error Rate	10.6 dB
Modulator Loss	1.1 dB
Demodulator Loss	1.9 dB
Required Eb/No	13.6 dB

The modulator and demodulator losses are representative of a carefully designed system operating in the 84 MBPS to 120 MBPS range. A data rate of 84 MBPS is used in developing the link budget

2.2.3 FREE SPACE LOSS

The free space loss, a function of the slant range, r, of the spacecraft from the ground station antenna, is given by

$$Ls = 20 \log (\lambda/4\ r)$$

where λ = the carrier wavelength

and r = the slant range.

Since the value of the carrier frequency considered is 8.2125 GHZ and the slant range computed from Section 2.1 for a 5^{o} ground elevation angle is 2573 km, the maximum free space loss is 178.9 dB.

2.2.4 POINTING LOSS (Lp)

Because of the broad beamwidth of the transmit antenna, as discussed in paragraph 2.2.8, it contributes little to pointing loss. The major contributor is the ground station pointing error due to noise in the autotrack subsystem. After acquisition it is expected that the antenna will track the spacecraft well within the 0.25 dB beamwidth and this value is used in the link budget.

2.2.5 POLARIZATION LOSS (Lpo)

Within the 0.25 dB beamwidth to which the ground station tracks the spacecraft, the ground station antenna polarization is very closely circular and contributes little to polarization loss. However, the wide beam spacecraft antenna is expected to have up to a 2:1 axial ratio over the 128° field of view. This contributes a polarization loss of about 0.5 dB.

2.2.6 ATMOSPHERIC LOSSES (La)

Atmospheric losses are taken as those due to oxygen and atmospheric water vapor attenuation and rain. For a standard atmosphere, oxygen and water vapor losses are presented in Figure 2-3. As shown, for a 5° elevation angle and a frequency slightly over 8 GHz, the attenuation is 0.5 dB.

Attenuation due to rain depends on the rainfall rate and the extent of rainfall around the receiving antenna at the time of overflight of the Landsat spacecraft. For a given site, data could be collected and a statistical analysis of losses due to rainfall performed. However, for the present purposes a 2 to 4 dB loss is included in the link calculations. For reference, 2 dB is the loss due to rain that is expected less than about 0.03% of the time in climates like New Jersey [2] for elevation angles greater than 20°. At a 5° elevation angle, a 4 dB loss is estimated.

Because the rain attenuation is a measured value, it includes oxygen and water vapor losses. That is, these values should not be, and are not, added to arrive at the atmospheric loss. Only the rain value is used.

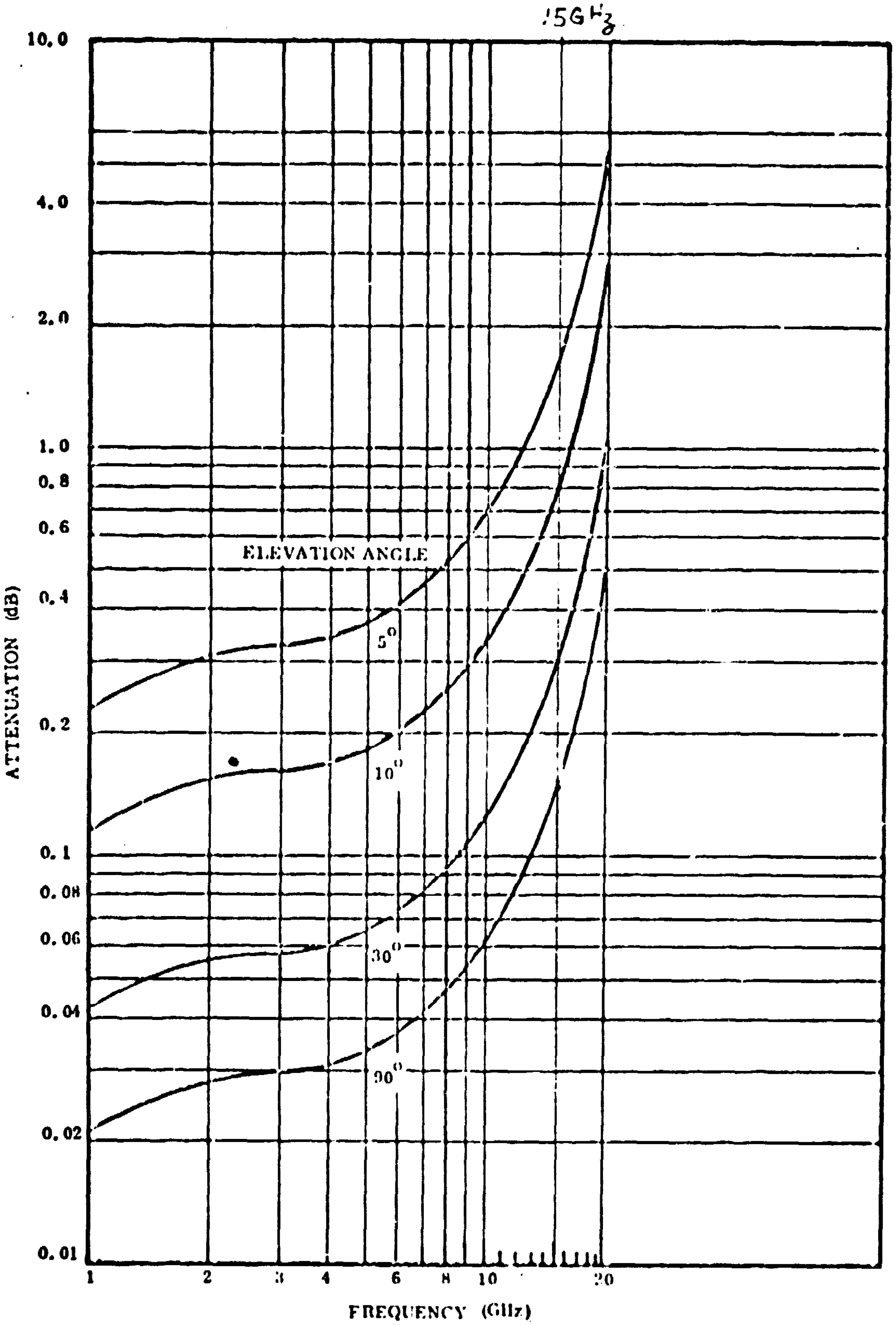

Figure 2-3. Attenuation Due to Oxygen and Water Vapor. From CCIR Documents of the XIth Plenary Assembly, 1966, Vol. 4, pp. 234-255

2.2.7 LUT SENSITIVITY (G/T)

For the direct readout station receiving system, a 10 meter (33 ft) diameter dish, similar to those currently used in existing Landsat receiving stations is assumed. An antenna of this diameter is within the limits of current technology for X-band tracking and communications with low earth orbit spacecraft and can be obtained at modest cost.
Table 2-2 shows the estimated gain of such an antenna to be 55.2 dBi.

Table 2-2. Antenna Gain Estimate

Gain of Ideal 10 meter Antenna at 8.212 GHz - dBi	58.7
Aperature Illumination Efficiency - dB	-0.8
Spillover Efficiency - dB	-0.9
Blockage - dB	-0.2
Surface Tolerance (.035" rms) - dB	-0.4
Primary Pattern Phase Error - dB	-0.1
VSWR Loss - dB	-0.2
Gain at Antenna Terminals - dB	56.1
Feed Losses - dB	0.7
Feed VSWR Losses - dB	0.2
Gain at LNA* Input - dBi	55.2

System noise temperature is made up of components due to sky noise, thermodynamic temperature of the antenna, losses between antenna and receiving amplifier (paramp), and paramp noise temperature. Table 2-3 shows the estimated receiving system noise contributions. Sky noise and thermodynamic temperature of the antenna depend on the elevation angle and result in a value of effective noise temperature decreasing from 60^{o}K at 5^{o} elevation to 30^{o}K at 90^{o} elevation (clear weather) which cannot be reduced substantially.

Antenna feed and waveguide contribute approximately 43^{o}K due to inherent losses, for a total effective noise temperature at the antenna port of the paramp of 73^{o}K to 103^{o}K.

*LNA = Low Noise Amplifier

Table 2-3. Estimated Receive System Noise Temperature

	Elevation Angle 5^{o}	Elevation Angle 90^{o}
Antenna Noise Temperature - ^{o}K	60.0	30.0
Attenuation (0.7 dB loss) Noise - ^{o}K	43.0	43.0
LNA Noise Temperature - ^{o}K	100.0	100.0
System Noise - ^{o}K	203.0	173.0

Paramp technology, using cryogenically cooled amplifiers can achieve LNA noise temperatures below 50^{o}K. More convenient to use are the thermoelectrically cooled paramps. These can achieve noise temperatures of less than 100^{o}K, which appears adequate, and their use is assumed.

When the specified antenna gain is combined with these values of system noise temperature, the resulting receiving system sensitivity (G/T) is between 32.1 and 32.8 dB $^{o}K^{-1}$, depending upon the elevation angle.

2.2.8 EIRP REQUIRED

Taking into account the preceding factors, and including a 3 dB system margin the relationship of Required EIRP vs. ground elevation angle shown in Figure 2-4 may be plotted. The curve provides the basis for selecting the transmitter amplifier and antenna.

System margin is discussed in Section 2.4

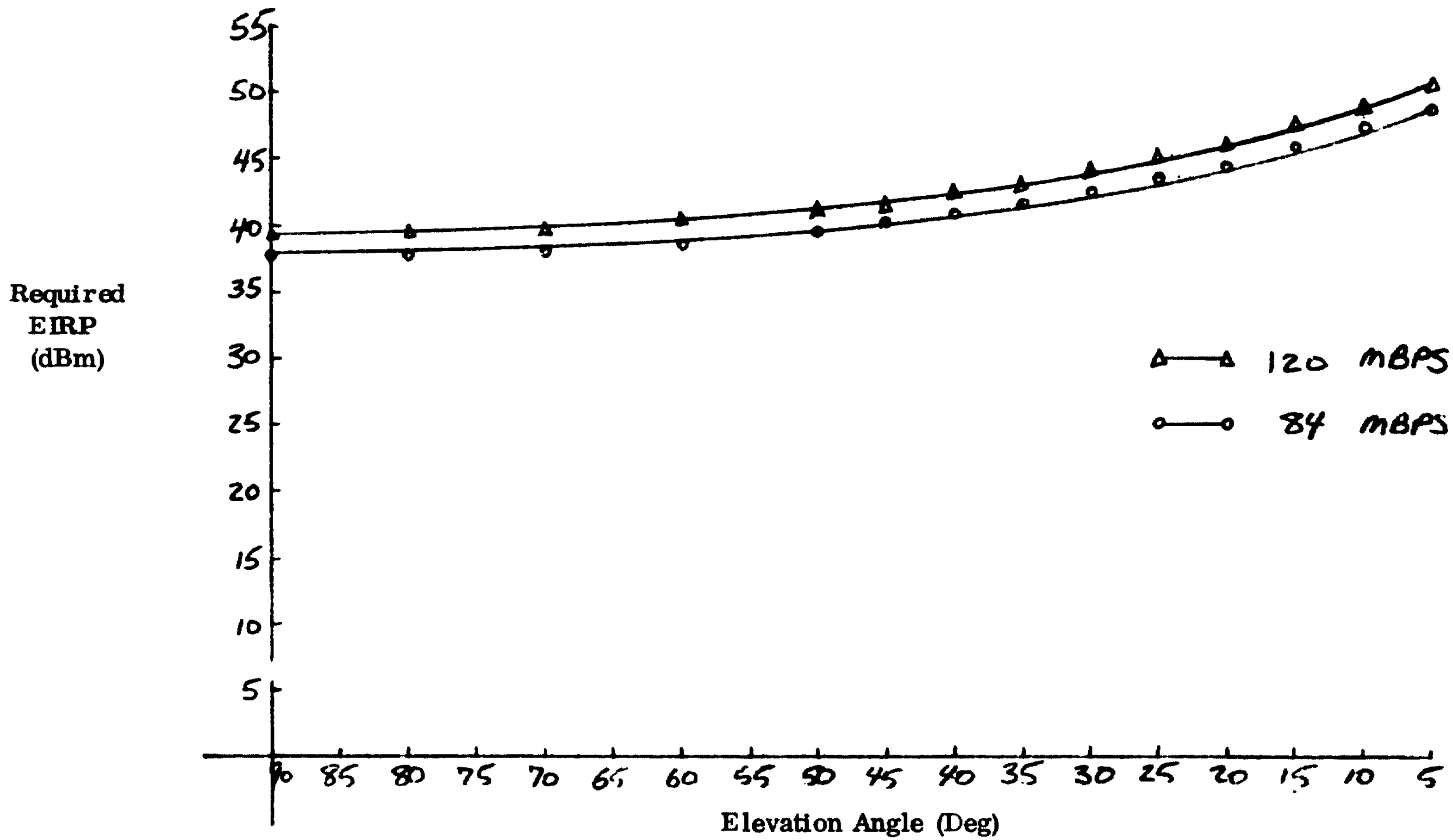

Figure 2-4. Required EIRP vs. Elevation Angle

2.3 SPACECRAFT EIRP

2.3.1 ANTENNA GAIN PATTERN

From the requirement to provide a readout capability at ground station elevation angles of 5° and higher, the spacecraft antenna coverage cone angle of 128° is established. The varying space loss, atmospheric attenuation and ground station system temperature with ground station elevation angle make possible the use of a spacecraft antenna having up to about 14 dB less gain at nadir than at $\pm 64^{\circ}$, a fact that can be used to maximize system performance at the extremes of the coverage circle. That is, the spacecraft antenna gain at $\pm 64^{\circ}$ can be maximized by decreasing the gain at smaller angles.

Figure 2-4 illustrates the idealized spacecraft antenna pattern. Among the many approaches to synthesizing the desired pattern are:

1. A flared conical horn with central blocking element to control the $G(64^{\circ})$ to $G(0^{\circ})$ ratio.

2. A dielectric lens or rod combined with a conical horn. The length and shape of dielectric determines the $G(64^{\circ})/G(0^{\circ})$ ratio.

3. A scaled version of the 2.2 GHz Landsat earth coverage antenna that uses a crossed dipole pair, supported and fed by a coaxial feedline in front of a roughly 1.5λ circular ground plant.

The lens approach [3] provides good design flexibility for pattern synthesis and has been used for producing conical beams with peaks at $\pm 24^{\circ}$ off nadir. The feasibility of using a dielectric rod or lens beam shaping for the larger angle of $\pm 64^{\circ}$ would have to be established.

The scaled Landsat C S-band design is quite small. The coaxial line supporting the dipole is 3.5" long at 2.2 GHz which scales to .94" long and the coaxial line is of smaller diameter. A $\lambda/2$ dipole scales to 0.72" long. The power handling capabilities of this approach would have to be established before it is used.

The first approach appears preferable at the present time. A similar design approach was used in the evolution of a high performance microwave relay antenna [4] . Figure 2-5 shows a cross section of the proposed conical horn antenna. The metal central cone shape determines the ratio of $G(64^{\circ})/G(0^{\circ})$.

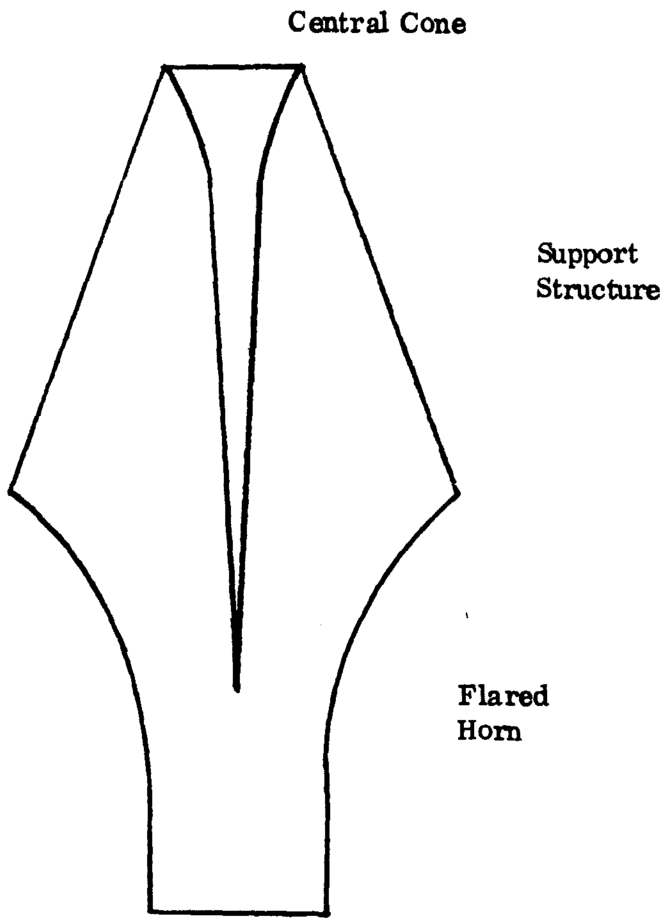

Figure 2-5. Cross Section of Flared Conical Horn with Central Blocking Element

An estimate of an achievable pattern is shown in Figure 2-6 along with the idealized pattern. The calculated antenna gain for a horn with this pattern is 5.50 dBi at $\pm 64^{o}$ with a minimum gain of roughly 0 dBi at $\pm 27^{o}$. Experience with antennas producing similar patterns indicates the calculated gain is optimistic by about 1.2 dB. Consequently the gain at $\pm 64^{o}$ is taken as 4.3 dBi for the link calculations.

2.3.2 SPACECRAFT TWTA.

The baseline transmitter power is taken as 40 watts (46.0 dBm). Based on the 50 watt transmitter tube under development for the DSCS III program, the tube has an efficiency of approximately 33%.

2.3.3 EIRP AVAILABLE

Combining the transmitter power and the spacecraft antenna gain, the available spacecraft EIRP as a function of ground elevation angle is obtained. This relationship is presented in Figure 2-6.

The use of 40 watts in calculating the EIRP provides for 1 dB of transmitter circuit loss or tube backoff. As can be seen from Table 2-1, the EIRP required for a 5^{o} elevation angle is 48.8 dBm. If a 4.3 dB gain is assumed for the spacecraft antenna at this angle, then a gain of 44.8 dBm is required from the power amplifier. This is more than adequately provided by the 40 watt (46 dBm) tube with 1 dB of circuit losses.

2.4 SYSTEM MARGIN

Plotted in Figure 2-7 are the EIRP required and the EIRP available (as previously discussed) as a function of ground elevation angle. Effective link margins, or the difference between the two curves of Figure 2-7, are plotted in Figure 2-8, also as a function of ground elevation angle.

The 3 dB margin included in the link budget, called system margin, is intended to provide for the unexpected such as receiver sensitivity loss with time, equipment malfunction and tracking errors. The effective link margin can be used during further system development to reduce performance requirements such as transmitter power and earth station sensitivity.

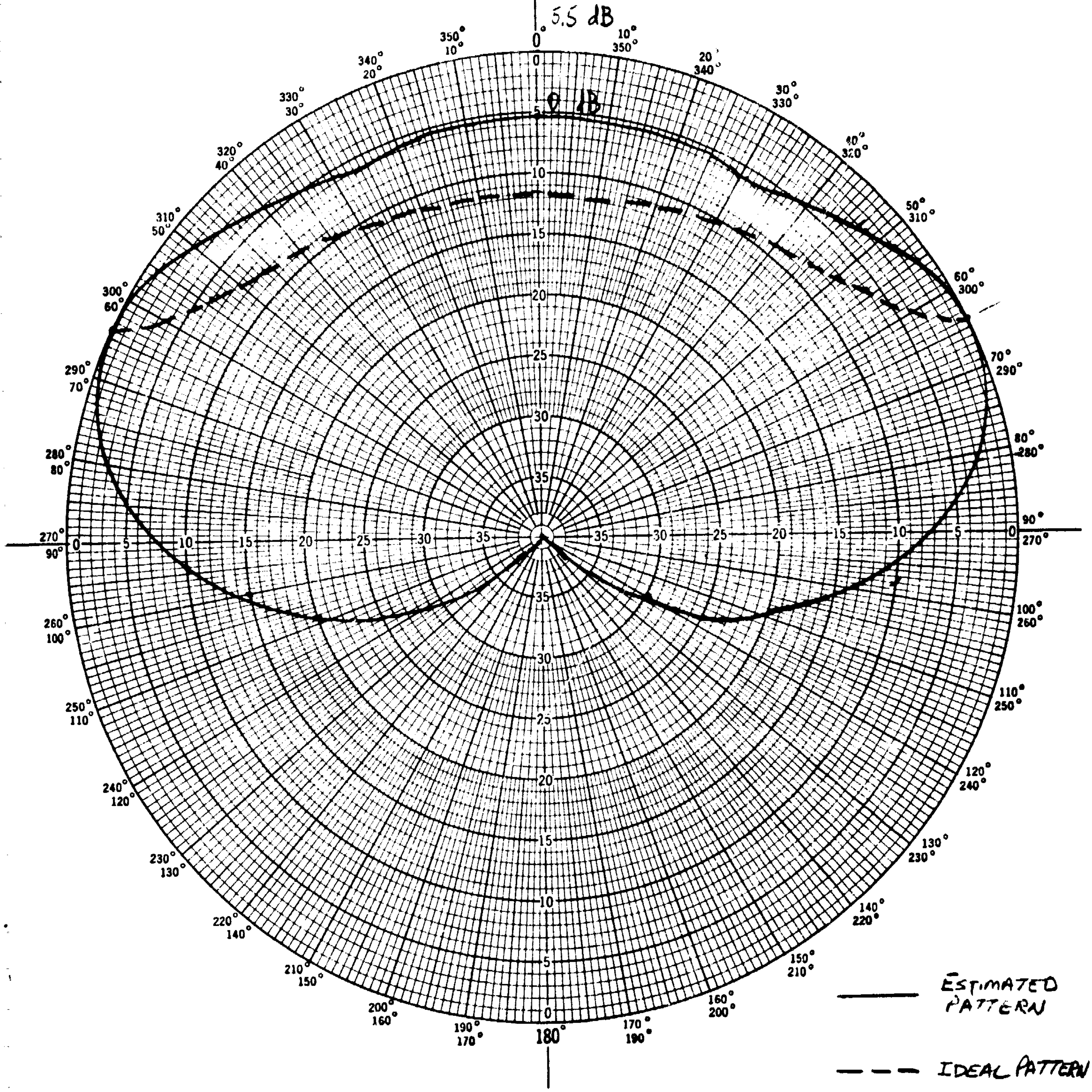

Figure 2-6. Estimated Spacecraft Antenna Pattern

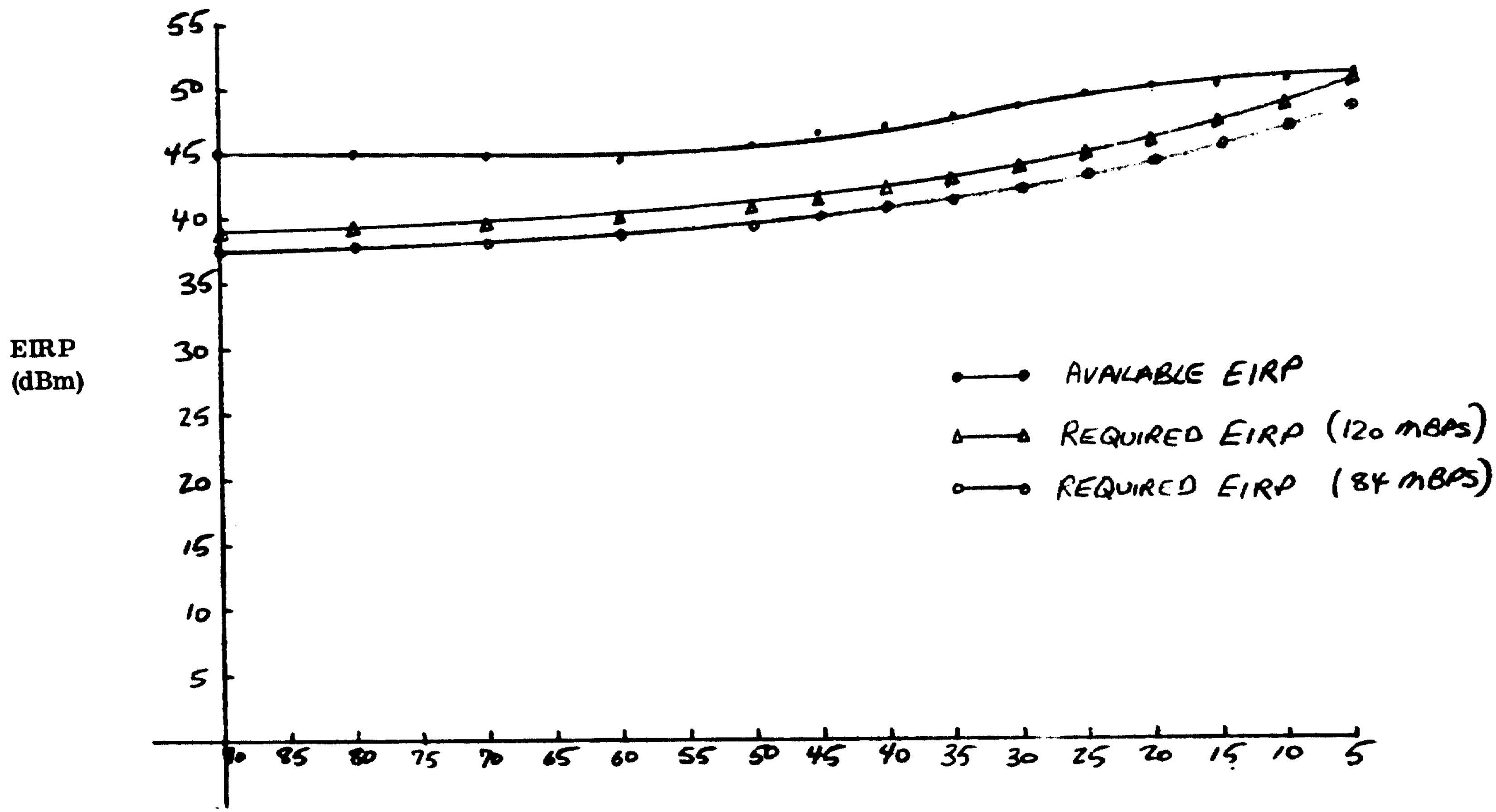

Figure 2-7. Required and Available EIRP vs. Ground Station Elevation Angle

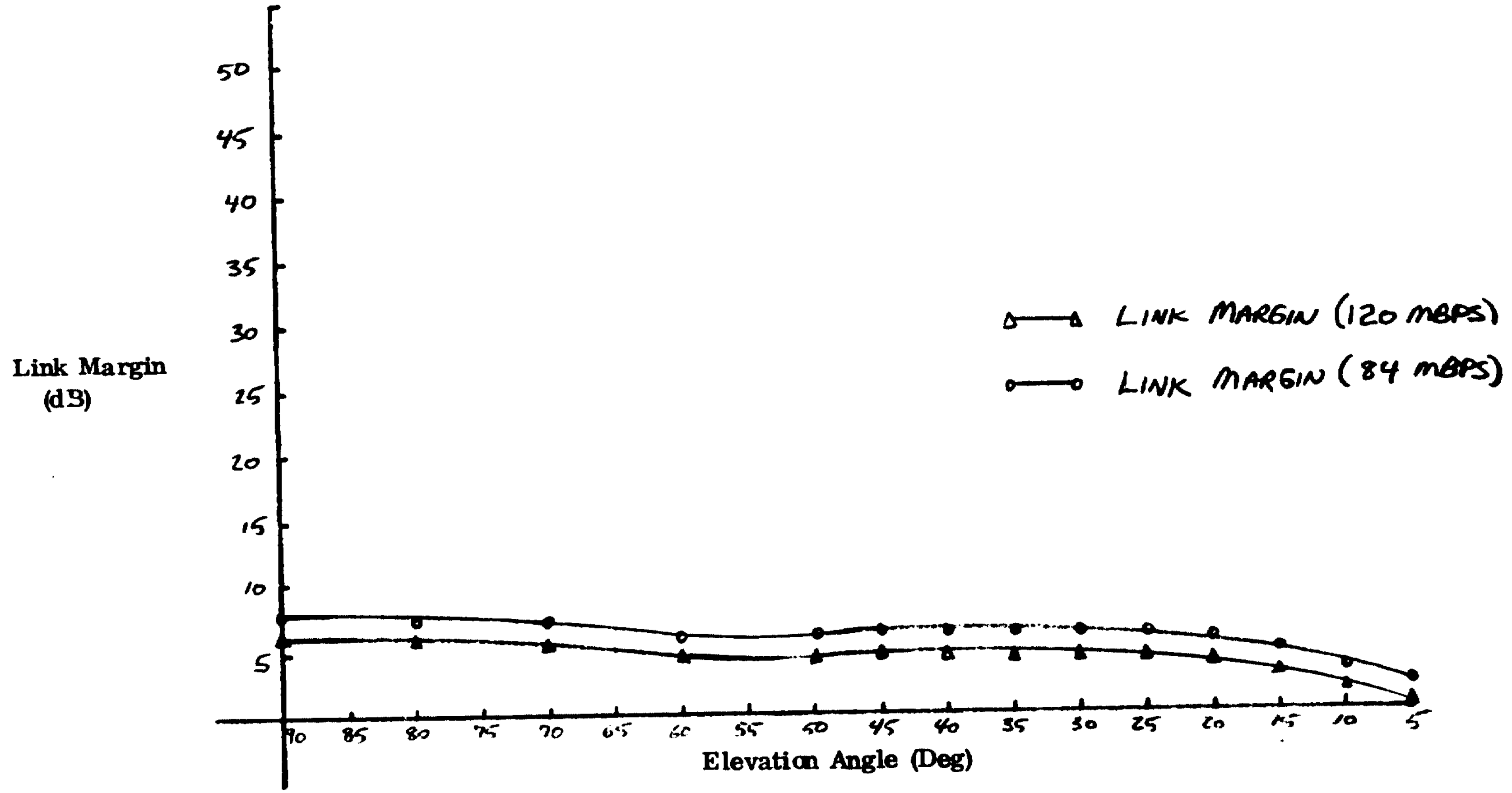

Figure 2-8. Link Margin vs. Ground Station Elevation Angle

2.5 NARROWBEAM SPACECRAFT ANTENNA ALTERNATIVE

The use of a narrowbeam, higher gain, spacecraft antenna makes possible a reduction of the transmitter final amplifier power rating, the use of a smaller ground station antenna, a higher noise temperature receiver or a combination of these. These advantages are obtainable at the cost of increased spacecraft antenna complexity to provide the required antenna beam steering and a limitation on the number of stations that can simultaneously receive data from the spacecraft to one or at least those simultaneously within the beamwidth.

There are several constraints limiting the use of narrowbeam antennas. With respect to reducing the required ground station antenna size and increasing the noise temperature, which can be combined in the G/T sensitivity factor, the ultimate limitation is the allowable flux density at the ground. With respect to reducing transmitter power rating, the limitations are the antenna and steering equipment size and weight and the command rate requirement if open loop pointing is used for beam steering.

Several antenna possibilities exist for realizable beam steering; phased arrays, switching between several antennas pointed so as to collectively cover the required field of view and mechanical scanning of an antenna.

Because of the wide scan angle required, the phased array approach requires a large number of elements (perhaps 49 or more) and, with the required phase shifters, appears relatively complex. For that reason the following discussions is confined to beam switching and mechanical scanning.

As the following discussions shows, for a modest increase in spacecraft antenna complexity significant reductions in ground station sensitivity requirements or spacecraft transmitter power can be obtained.

2.5.1 FLUX DENSITY LIMITATIONS AND LUT RECEIVER REQUIREMENT REDUCTION

Power flux density at the earth's surface produced by emissions from earth exploration, space research, and fixed satellites is regulated by International Telecommunications Union (ITU) as revised by the World Administration Radio Conference (WARC), Geneva, 1971. Table 2-4 summarizes the applicable regulations.

Table 2-4. Flux Density Limits

Angle of arrival of signal above horizontal plane (degrees)	Maximum flux density in any 4 kHz band (dBw/meter^2)
$0 \leq \psi \leq 5^{o}$	-150
$5^{o} \leq \psi \leq 25^{o}$	$-150 + \frac{\psi-5}{2}$
$25^{o} \leq \psi \leq 90^{o}$	-140

These flux density limits may be translated into an allowable EIRP from the spacecraft, which is a function of its orbit altitude, slant range, elevation angle of the ground station and the data rate required. The equation governing this is

$$EIRP_{MAX} = \text{Flux limit} + 10 \log (4\pi r^2) + 10 \log \left(\frac{BW}{4000}\right)$$

where:

r = slant range to the spacecraft, in meters

BW = Bandwidth required to carry the data rate, in Hz.

The LFo is expected to use QPSK modulation, which will result in a required bandwidth of one half the data rate. The governing equation becomes

$$EIRP_{MAX} = \text{Flux limit} + 10 \log (4\pi r^2) + 10 \log \left(\frac{DR}{8000}\right) \qquad (6)$$

Figure 2-9 shows a plot of the allowable EIRP, from which it is seen that more than a 58 dBm EIRP may be used without exceeding the flux density limitations.

To illustrate the use of this allowable EIRP to reduce the ground station requirements consider the maximum EIRP requirement derived in the link budget, Table 2-2 of 48.8 dBm. This is 9.2 dB below the maximum allowed by the flux density restrictions. This 9.2 dB if it were used to reduce the ground station antenna size, would permit reducing the antenna diameter from the baseline 10 meter diameter to about 3.5 meters.

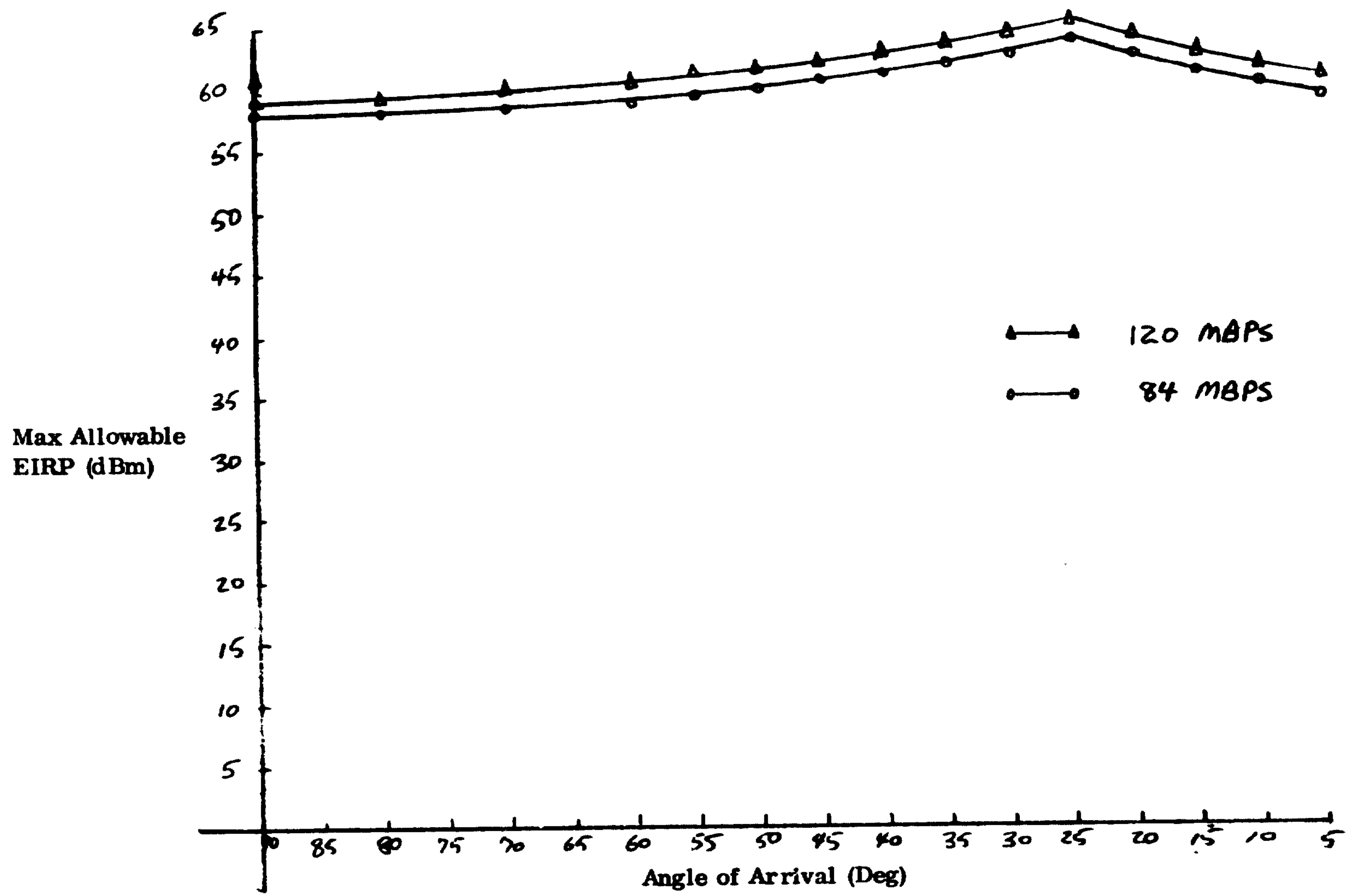

Figure 2-9 Maximum Allowable EIRP vs. Angle of Arrival

Inclusion of a pointing loss of 3 dB to ease the beam steering requirements, that is, the spacecraft antenna would need to keep the LUT within its 3 dB beamwidth, increases the required LUT antenna diameter to about 5 meters. This is still a significant size reduction.

Retaining the baseline 40 watt (46 dBm) transmitter, the 58 dBm EIRP can be obtained through the use of a 12 dBi gain antenna on the spacecraft which can be achieved, for example, through the use of a horn antenna with about a 2 inch diameter aperture.

2.5.2 LFO TRANSMITTER POWER REDUCTION

Retaining the 10 meter LUT antenna and the 32.1 $dB^{o}K^{-1}$ receiving sensitivity, permits reduction of the transmitter power required through the use of a higher gain transmitting antenna. For example, a 12 dBi gain (at the half power points in this case, i.e., a 15 dB peak gain), antenna permits the use of 36.8 dBm transmitted power to achieve the 48.8 dBm EIRP required by LUT's having elevation angles of 5^{o}. Allowing 1 dB for transmit circuit losses, the transmitter requirements can be satisfied by a 6 watt transmitter - a significant reduction from the baseline 40 watt transmitter.

2.5.3 LFO ANTENNA DESIGNS

Although the required radiating antennas may be realized several ways, for convenience the following discussion assumes that horns are used. Also for convenience, the discussion is in terms of the 15 dBi peak gain antenna. The modification required for the case of a 12 dBi antenna are straightforward.

A 15 dBi peak gain horn has an aperture diameter of about 3 inches and a beamwidth of about 40^{o}.

A mechanically steerable antenna using such a horn is conceptually simple. The transmitter amplifier is connected to the antenna by rotary joints. Two rotary joints are required, each driven by a stepping motor. In the off nadir direction two steps of about 32^{o} each are required. Around nadir steps in increments of 45^{o} are required.

Command rates for such an antenna, in the worst case off zenith pass, are a maximum of about 1 per 30 seconds which is very reasonable.

An alternative to the mechanically scanned antenna is an array of fixed horns pointed so that they collectively cover the field of view. The intent here is to replace the stepping motors with switches to successively connect the appropriate antenna to the transmitter. The design might consist of two rings of horns. The first ring contains 8 horns, each given a 15 dBi gain uniformly distributed around a circle and each pointed about 64° off nadir. A second ring of, perhaps, 4 smaller horns, each giving 10 to 12 dBi gain and pointed approximately 30° off nadir completes the array. In contrast to the mechanically scanned antenna, which gives roughly uniform EIRP over the field of view, the switched array design provides lower EIRP at near nadir angles than at the edge of view which is satisfactory. The second design then contains perhaps 12 horns and requires switching between them.

Command rates are about the same or lower for the second design.

2.5.4 CONCLUSIONS

The use of narrow beam spacecraft transmit antennas appears feasible and offer possible savings in ground station equipment and spacecraft transmitter power requirements.

3.0 SIGNAL ACQUISITION AND TRACKING

The beamwidth of a 10 meter diameter dish antenna, used at X-band is 0.26^{o} (3 dB beamwidth). Thus, the antenna must be positioned such that the line of sight from it to the spacecraft is less than 0.26^{o} from the antenna boresight for rapid initial monopulse tracking acquisition. In addition it is desirable to maintain pointing accuracy of better than 0.04o in order to maintain pointing losses to under 0.25 dB.

With the expected C/No (carrier to noise density ratio) of more than 92 dB, maintaining tracking to this accuracy presents no serious problem.

Initial pointing accuracy based on predicted orbits and equipment pointing errors should be less than 0.26^{o}. It is expected that many of the currently used Landsat ground stations have the essential capabilities.

A complication is the tracking of the Landsat spacecraft thru a zenith pass. The usual pedestal for direct readout stations used for Landsat 1 and 2 data acquisition is an Elevation over Azimuth mount. This type of mount suffers from the problem of requiring extremely high slew rates for spacecraft passes which are overhead or nearly overhead. For current systems, using S-band, the broader beam angle of the antenna permits the use of a programmed follower which enables tracking to be maintained. The same approach is available for use at X-band. However, because of the narrower beamwidth it is expected that when the spacecraft is in an area centered at zenith, about 1^{o} wide and 5^{o} along the zenith path data, will be missed.

4.0 SUPPORTING GROUND STATION EQUIPMENT

Representative supporting ground station equipment requirements, design and costs are presented in this section. Ground station equipment considered include the antenna, pedestal subsystem, antenna feed electronics, tracking control subsystem and the receiver subsystem through the low noise amplifier (LNA). The demodulator, not included in costs, is assumed to contain the required down conversion equipment. It is also assumed that an appropriate automatic gain control signal is available from the demodulator to indicate signal acquisition and similarly, video from an envelope detector is available for autotracking purposes.

Except for modifications dictated by the different carrier frequency and data rate (bandwidth) requirements, the X-band direct readout ground station design for the Thematic Mapper can be very similar to that of the Landsat S-Band Multispectral Scanner readout ground stations. Therefore, the ground station design and costs are developed by extrapolation from the S-band ground stations. In addition, estimated costs to modify existing S-band stations to operate at X-band are presented.

4.1 REQUIREMENTS SUMMARY

Major requirements are given in Table 4-1. In general, azimuth over elevation type pedestals are relatively lower cost. For this reason, and in recognition of the fact that many of the Landsat readout stations currently employ such pedestals, the requirements are written to make their use acceptable.

Because of the narrower beamwidth of a given aperture at X-band than at S-band, signal loss during a zenith pass is anticipated. To minimize the outage time a programmed antenna pointing control is required. The control anticipates such a pass and takes the antenna through the az-el trajectory that minimizes the outage time.

4.2 REPRESENTATIVE DESIGN

Table 4-2 summarizes the major features of a ground station satisfying the requirements.

Table 4-1. Ground Station Major Requirements Summary

Receiving Subsystem (Reflector, Antenna Feed and LNA)	
G/T (at 5° Elevation Angle)	32.1 $dB^{\circ}K^{-1}$
Operating Center Frequency	8.2125 GHz
RF Bandwidth (0.5 dB)	>60 MHz
Antenna Beamwidth, half power	>0.25 Degr.
Antenna Electronics and Feed Configuration	o Provide Autotrack capability o Circular Polarization
Pedestal Subsystem	
Azimuth Angle Range	360°
Elevation Range	0° to 90°
Slew Rates and Acceleration	Minimal Signal Outages during Near-zenith pass
Tracking Control Subsystem	
Type	o Autotrack with Zenith Pass Program Control
Open Loop Pointing	o Programmable mode to provide rapid acquisition as the spacecraft rises over horizon.

Table 4-2. Representative Ground Station Design

Antenna & Receiving Subsystem	
Reflector Diameter	10 meter
Surface Tolerance	0.04 inches rms
Gain at 8.2125 GHz	55.2 dBi
Feed Electronics	5 horn monopulse
LNA	Parametric Amplifier Noise Temp: 100 ^oK
Beamwidth (3 dB) at 8.2125	0.26^o
System G/T Referred to Antenna Port (at 5^o Elevation Angle)	32.1 dB $^oK^{-1}$
Pedestal Subsystem	
Azimuth Range	±210^o
Elevation Range	0^o to 89^o
Velocity	
Azimuth	$\geq$ 22^o/sec
Elevation	$\geq$ 9^o/sec
Acceleration	
Azimuth	$\geq$ 10^o/sec
Elevation	$\geq$ 9^o/sec
Tracking Control Subsystem	
Type	Autotrack: Pseudo Monopulse
Zenith Pass	Program Control to anticipate Zenith Pass and take Az-El trajectory that minimizes outage time.

4.3 REPRESENTATIVE COSTS

Representative costs to replace existing Landsat S-Band ground stations with X-Band stations for Landsat D Thematic Mapper direct readout are presented in Tables 4-3 and 4-4. Two cases are costed (1) a complete station and (2) modification of an existing S-Band station to adapt it to X-Band operation.

Station modification costs assume that the existing earth station antenna reflector surface tolerance is small enough to support X-Band operation. That is, the surface tolerance is no more than 0.06 inches rms and preferably less than 0.04 inches rms.

Table 4-3. Representative Costs to Install an X-Band Station

Antenna Subsystem	$35,000
10 Meter Reflector Spares Feed Support	
Pedestal Subsystem	202,000
Base Extension Side Arms Counter Weights Drive Chains	
Feed Electronics	195,000
LNA, 5 Element Feed, Comparators, Directional Couplers, Preamps Scan Circuits	
Tracking and Control Electronics	140,000
SCR Motor Drives, Servo Control and Compensation, Control Unit Display Unit	
Cables, RF and Control	14,000
Installation	50,000
TOTAL	$636,000

Table 4-4. Representative Costs to Modify S-Band Station

Feed Electronics	\$195,000
Electronics Installation and System Testing	6,000
Total	\$201,000

Spare parts costs and costs of any station personnel training is not included in either estimate.

5.0 SUMMARY AND CONCLUSIONS

The results of the preceeding analyses support the use of an X-band carrier frequency for the Landsat D direct readout link. It has been shown through analysis that the transmission link contains acceptable margin and that the required ground station equipment is not unduly complex or expensive.

The 5° minimum ground station elevation angle and 2362 km coverage zone radius reception requirements may be met either by a conical pattern or steerable-type antenna on the spacecraft. The conical pattern antenna requires a 10 meter diameter ground station antenna. A steerable antenna on the spacecraft will not require as large a ground antenna but violates the intent of NASA's "open skies policy". The TWT power transmitter required by either configuration is available.

An investigation of representative costs of the "front end" equipment required by an X-band ground station indicates that the equipment is slightly more expensive than that for an S-band (MSS) ground station. Further, the cost of modifications to an S-band station for conversion to X-band, including feed electronics packaging and additional testing is minimal.

6.0 REFERENCES

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